VI. Transport Lines

A. Introduction

Four beam transport lines are used in the Antiproton source to connect the Debuncher and Accumulator, and to provide a path to and from the Main Injector beamlines:

- AP1 transports 120 GeV protons extracted from the Main Injector to the pbar production target via the P1 and P2 lines. When oriented at 8 GeV, AP-1 delivers antiprotons extracted from the Accumulator towards the Main Injector. Protons can also be "reverse injected" from the Main Injector to the Accumulator for shot tune-up or studies.

- AP2 transports 8 GeV antiprotons from the target station and injects them into the Debuncher ring. Protons can be reverse injected from the Debuncher into the AP2 line for studies. On infrequent occasions magnet polarities are reversed in the AP-2 line and the target and collection lens removed to allow 8-GeV protons from the Main Injector to be transported to the Debuncher.

- AP3, in conjunction with AP1, carries extracted 8 GeV antiprotons from the Accumulator to the Main Injector and delivers 8 GeV "reverse" protons from the Main Injector to the Accumulator.

- The D to A line transfers antiprotons between the Debuncher and Accumulator. Protons that have been reverse injected into the Accumulator can also be transferred into the Debuncher for studies.

Maps of the beamlines can be found in the Appendix at the end of this section. Information on electrical, cooling water and vacuum systems are consistent with those found in the rings, details can be found in the Utilities chapter of this book. The Diagnostics chapter of this book contains information about Beam Position Monitors (BPM's), Beam Loss Monitors

Beam line	Dipoles		Quads		Trims	
	Power supplies	Magnets	Power Supplies	Magnets	Power Supplies	Magnets
AP1 120 GeV	M:H10*	PB*	M:Q10*	PQ*	M:HT10*	PQ*-HT
AP1 8 GeV	M:H20*	PB*	M:Q20*	PQ*	M:HT10*	PQ*-HT
AP2	D:H7**	IB*	D:Q7**	IQ**	D:HT7**	IQ**-HT
D to A	D:H8**	TB*	D:Q8**	TQ*	D:HT8**	TQ*-HT
AP3	D:H9**	EB*	D:Q9**	EQ**	D:HT9**	EQ**-HT

Table 1 Naming conventions

(BLMs) Secondary Emission Monitors (SEM's) and other diagnostics found in the transport lines.

B. Naming Conventions

The naming convention used in the transport lines can be confusing, as there are both magnet names and power supply names. Magnets are generally identified by their installation names since the power supplies are often connected to multiple loads. Tables 1 summarizes magnet and power supply names for the beamlines.

The leading letter in the magnet names represents which beamline it's a part of; for AP1 magnets the "P" is for "Proton", in AP2 the "I" is for "Injection", in the D to A line the "T" is for "Transfer" and in AP3 the "E" is for "Extraction". The second letter is somewhat intuitive, "B" is for "bend" (dipole), and "Q" is for "quadrupole". Trims are identified with a hyphenated extension, HT (VT) for a horizontal (vertical) trim. Dipoles are assumed to be horizontal unless otherwise indicated, e.g. IB1 is a horizontal dipole while IBV1 is a vertical dipole. Note that AP1 line trims have a single power supply that can be used for either 8 GeV or 120 GeV operation.

C. Kickers and septa

Beam transfer to and from the Pbar rings is accomplished with kicker and septum pairs. An injection septum bends the beam from a transport line into an accelerator and an injection kicker deflects the beam on to the closed orbit. An extraction kicker deflects beam from the closed orbit into the field region of a septum, which in turn bends the beam into a transport line. There are two styles of kickers in the antiproton source, an Accumulator style and a

Debuncher style that both produce magnetic fields of approximately 500 Gauss. Septa also come in two different styles, although all but the Accumulator extraction Lambertson are made up of a single-turn design.

1. Kickers

The Debuncher injection and extraction kickers are ferrite single-turn transmission line pulsed magnets that are similar in design to those found in the Booster, Main Ring and Tevatron. The 200 nanosecond fall time for the injection kicker and rise time for the extraction kicker required some

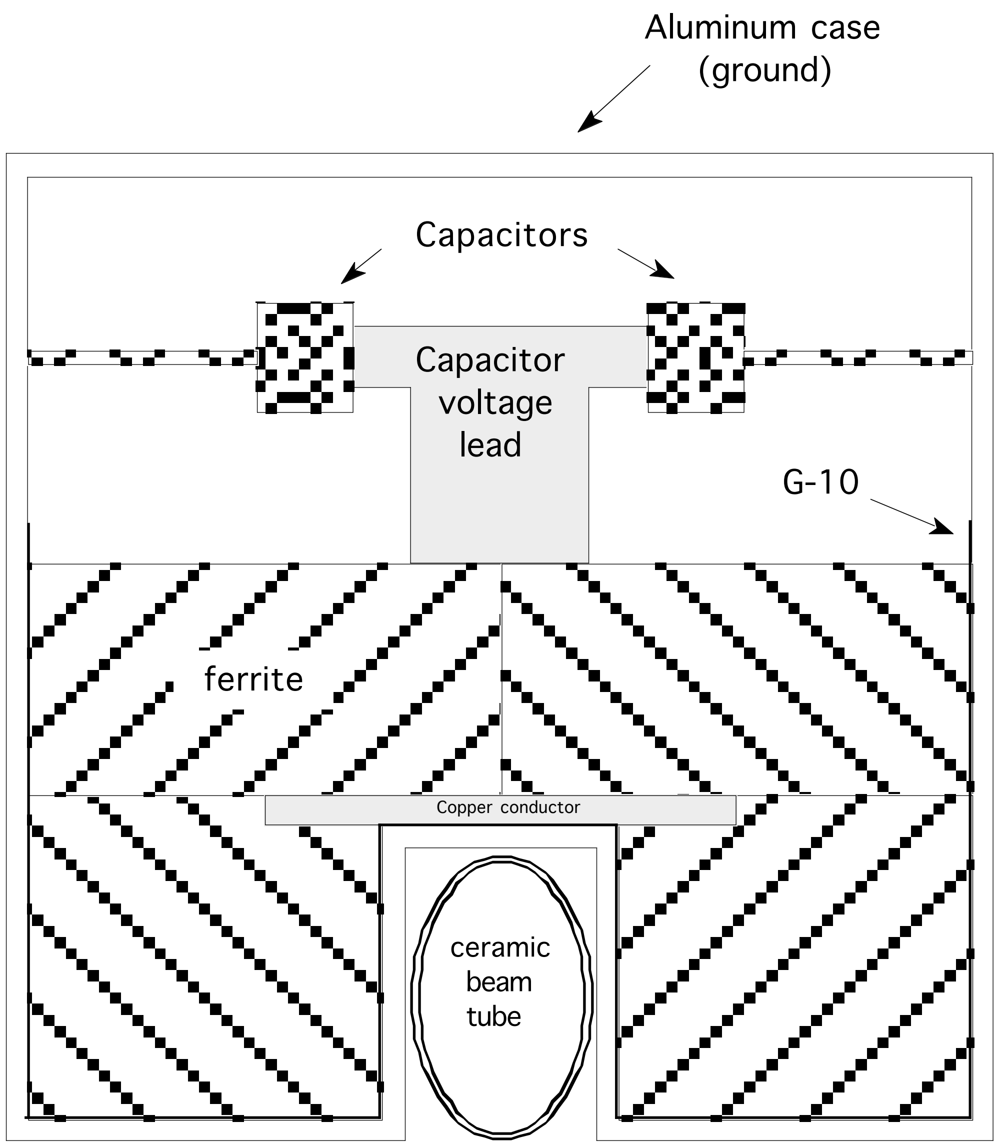


Figure 6.1 End view of Debuncher injection kicker

modifications from kickers previously designed.

Debuncher kickers are made up of three separate modules to limit propagation delay. Figure 6.1 is an end view of the Debuncher injection kicker, use it as a reference in the following description. Each module is about a meter long and is made up of a series of 48 sets of 4 ferrite blocks about 1.8 cm thick stacked around a copper conductor. 12 pairs of capacitors are connected on one end to the central copper conductor that carries the current. The other end is connected to the aluminum case, which is grounded. The module case does not contain the beam tube, which is an external elliptical ceramic chamber 5.7 cm. x 4.1 cm. The module has a "c" shape that surrounds the beam tube on three sides, replacing Debuncher kicker modules doesn't require vacuum to be broken. With the central conductor and ferrites providing the inductance and the capacitors providing the capacitance to the circuit, the magnet electrically looks like a 10Ω transmission line. The ferrites, which are at high voltage like the conductor, are insulated from the outer case with G-10. The capacitors and capacitor leads are potted with an insulating rubber compound.

The Accumulator injection and extraction kickers bear little physical resemblance to their Debuncher counterparts although they are similar electrically. Many of the design considerations were driven by the need for a shutter to shield the antiproton core from the kicker pulse. The shutter is a plate of aluminum 5 mm thick and 3 m long. Three titanium arms "rock" the shutter in to and out of place and are driven through linkage by a DC stepping motor.

The Accumulator kickers have a cylindrical conductor surrounded by "c" shaped ferrites. The ferrites are specially prepared and handled to minimize outgassing. Capacitance in the kicker circuit is provided by distributing parallel plate capacitors along the length of the magnet. High voltage plates are attached to the center conductor and ground plates are located between the high voltage plates. The capacitors make use of an alumina ceramic as a dielectric as well as for various insulating components.

The A20 straight section contains both Accumulator kickers. The kickers are housed in tanks that are similar in appearance to stacktail pickup tanks. Large high voltage cables feeding into the kicker tanks distinguishes them from stochastic cooling tanks. Due to the ultra high vacuum requirements of

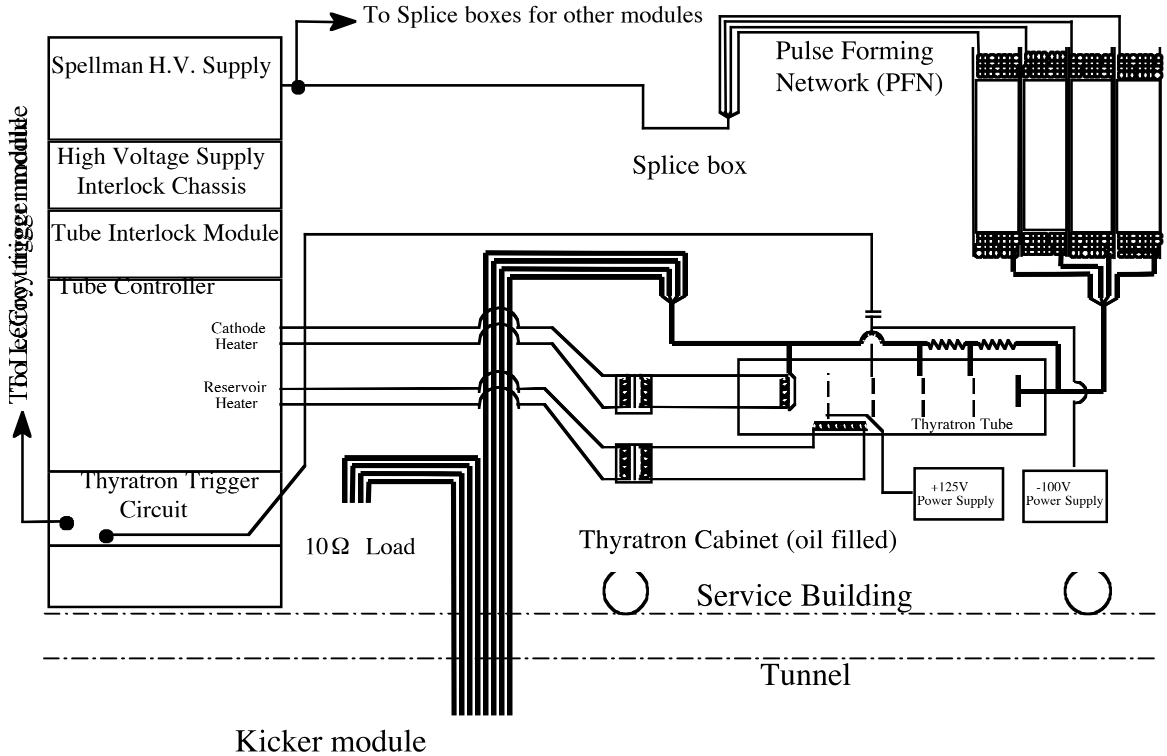


Figure 6.2 Kicker power supply

the Accumulator, the magnets and tanks are baked out along with other components during start-ups.

Power supplies are virtually the same for both Accumulator and Debuncher kickers. Figure 6.2 diagrams a typical kicker power supply and associated components. A hydrogen thyratron switch tube is used as a high voltage switch to allow the electrical current to pulse through the kicker. High voltage cable is coiled on large aluminum frames to provide a Pulse Forming Network (PFN) that helps form the shape and duration of the kicker pulse. During a typical stacking cycle the PFN's are charged up over about .5 sec to around 60 kV by a Spellman high voltage power supply. A LeCroy timing module provides a pulse to a kicker trigger module at the appropriate time which in turn "fires" the thyratron tube. This closes the circuit and allows a current pulse to pass through the kicker magnet to a 10Ω load. The thyratron tube is housed in an oil-filled cabinet located in the service building. The 10Ω load and PFN's are also located in the service building.

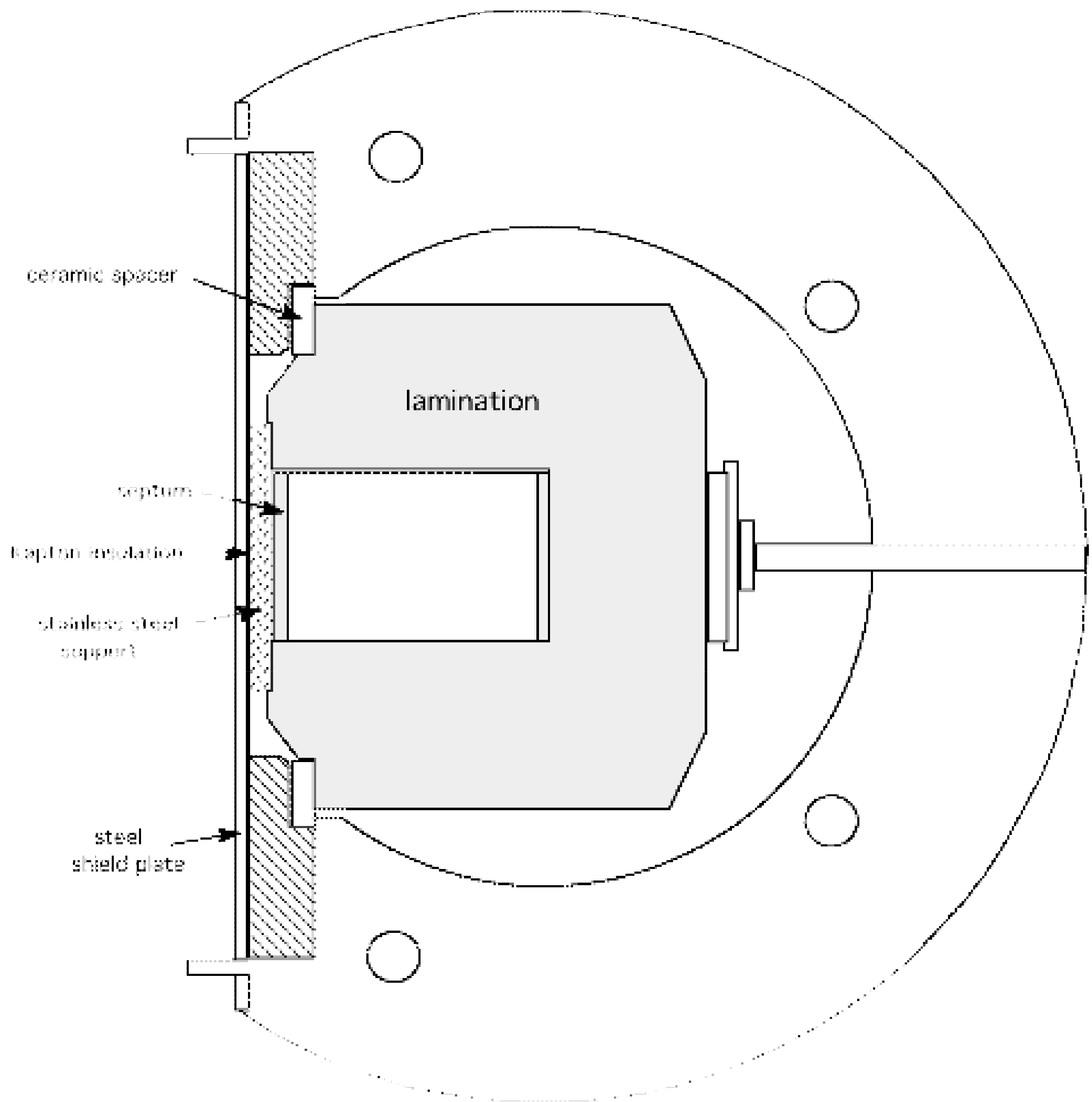


Figure 6-5 Debuncher extraction septum cross section

2. Septa

There are five septa magnets found in the pbar rings, four of them are of a single turn design. Debuncher injection and extraction as well as Accumulator injection (two septa are used here) utilize the single turn pulsed septum. Each septum is 2 meters long and is made by stacking "c" shaped steel laminations in a fixture with a slight (50 m radius) curvature for improved aperture. The vacuum enclosure doubles as a stacking fixture for the magnet. Figure 6.3 provides a cross section of a septum magnet. The septum itself is about 1.3 cm thick (the entire septum magnet assembly has a diameter of about 25 cm) and is made up of four parts. A copper conductor is bonded to a stainless steel plate, both carry the current pulse (the steel plate provides support). A sheet of kapton insulates the conductors from a low carbon steel plate used to magnetically shield the circulating beam adjacent to the septum magnet. The conductor carries up to 20,000 Amps to produce a field of 6,000 Gauss (as compared to 500 Gauss for the kickers).

The Accumulator extraction septum is of a Lambertson style made up of a field free region for circulating beam and a field region for extracted beam. The Lambertson is normally powered at all times to prevent tune and orbit shifts that would accompany changing its state. Stray fields in the "field free" region of the Lambertson are small enough to be compensated for.

D. AP1

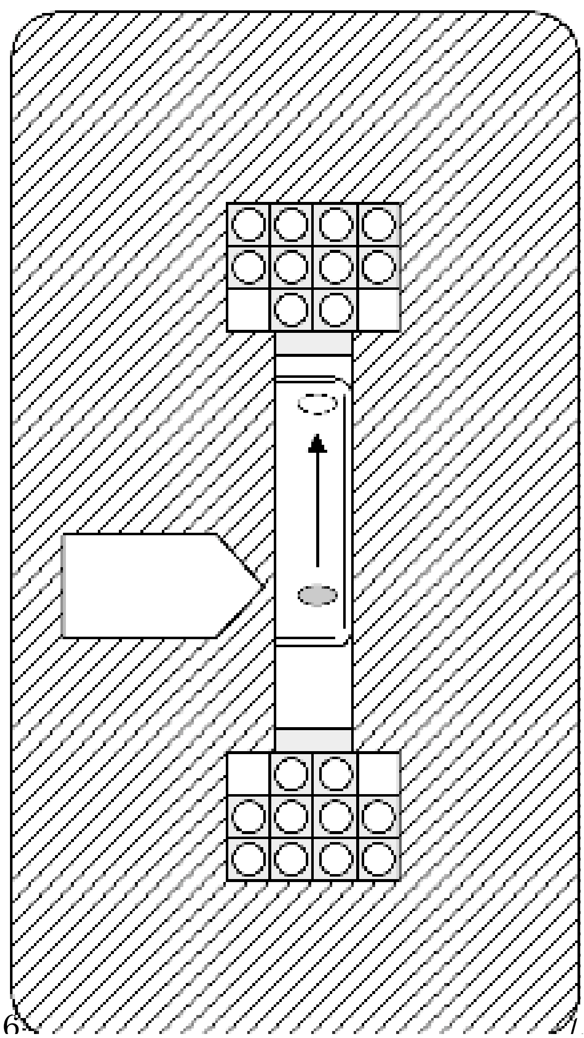
AP1 is approximately 570 feet long from the beginning of the extraction channel at F17 in the Tevatron enclosure to its terminus at the production target in the Vault. Vertically the line changes elevation from that of the P2 line in the Tevatron enclosure to seven feet higher at the production target. The AP-1 line's design was predominately driven by the need to efficiently transport 120 GeV protons from the old Main Ring to the target vault. An additional requirement was that the proton beam be focused to a small spot size on the production target. With this consideration in mind, the optics of the AP1 line can be broken down into three sections.

The first section runs from the extraction channel through PB5 (M:Q105) and was designed to cancel horizontal dispersion from the Main Ring. Though beam no longer comes from the Main Ring, the P2 line was designed so that the lattice functions closely matched those in the old Main Ring. The extraction channel is formed by two 162 inch-long Lambertson magnets followed by two 118.4 inch C-magnets that together bend the extracted beam upwards by 32.6 mrad. To make room for the extraction system, the Main Ring B-2 dipoles at F17-4,5 were replaced by a double strength dipole.

Downstream of the extraction channel, beam continues upward and to the outside (from the perspective of the P2 line). Horizontal trim P0-HT (M:HT100) follows which was originally intended to compensate for the difference in angle at F17 between the injected and extracted beams. A four-dipole string, composed of PB1&2 and PBR1&2 (M:HV100), is next. The second pair of dipoles in this string is rolled 38° to allow both vertical and horizontal bending (the "R" in the magnet name stands for "rolled"). Quadrupole PQ1 (M:Q101) follows and then AP1 passes through a 'sewer pipe' of about 76 feet and on to the Pretarget enclosure. The first element in this enclosure is trim PQ1-VT (M:VT101) and is closely followed by PQ2 (M:Q102). A series of four dipoles, the first of which is rolled 45°, PBR3 and PB3-5 (M:HV102), follow.

The second section acts to cancel vertical dispersion. It includes PQ3 (M:Q103), PQ4 (M:Q104), and PQ5A&B (M:Q105). A horizontal trim dipole, PQ5-HT (M:HT105), is next and is followed by two vertical dipoles, PBV1 & 2 (M:V105), which straighten out the upward climb of the beam towards the target.

The final section is composed of eight quadrupoles in four circuits, PQ6A&B (M:Q106), PQ7A&B (M:Q107), PQ8A&B (M:Q108), and PQ9A&B (M:Q109I&V). These elements provide the final focus for the proton beam to minimize the spot size on the target (leading to maximized antiproton yield). A horizontal trim, PQ7-HT (M:HT107), is located just upstream of the final quad doublet and a vertical trim, PQ8-VT (M:VT108), just downstream. These trims are used to finely tune the beam's position on the target to about ± 7 mm. This third section is coincidentally housed totally within the Prevault enclosure. Table 2 lists all AP1 magnetic elements.



Since AP1 operates at two significantly different energies, 8 and 120 GeV, all magnetic elements except trim dipoles are energized by two different supplies depending on the beam energy. Built in safeguards prevent both supplies from being energized simultaneously. The bipolar 25 Amp trim supplies are sufficient for both modes of operation.

AP1 line power supplies with the exception the supply powering the F17 Lambertsons and C-magnets (F2 for M:F17LAM and M:F17DC) are found in the F23 service building.

ELEMENT	120 GeV POWER SUPPLY	8 GeV POWER SUPPLY	TYPE OF DEVICE	COMMENTS
Lambertson #1	M:F17LAM	M:F17DC	F17 ramped/DC Lambertson	critical device rolled 6°
Lambertson #2	M:F17LAM	M:F17DC	F17 ramped/DC Lambertson	critical device rolled 6°
C-magnet #1	M:F17LAM	M:F17DC	F17 Vertical dipole	critical device
C-magnet #2	M:F17LAM	M:F17DC	F17 Vertical dipole	critical device
P0-HT	M:HT100	M:HT100	20” bump	
PB1	M:HV100	M:HV200	EPB dipole	critical device
PB2	M:HV100	M:HV200	EPB dipole	critical device
PBR1	M:HV100	M:HV200	EPB dipole	critical device, rolled 38°
PBR2	M:HV100	M:HV200	EPB dipole	critical device, rolled 38°
PQ1	M:Q101	M:Q201	3Q120 quad	
PQ1-VT	M:VT101	M:VT101	35” bump	
PQ2	M:Q102 M:Q102R=‘+’	M:Q202 M:Q102R = ‘-’	3Q120 quad	M:Q102R is a reversing switch
PBR3	M:HV102	M:HV202	AIRCO dipole	rolled 45°
PB3	M:HV102	M:HV202	AIRCO dipole	
PB4	M:HV102	M:HV202	AIRCO dipole	
PB5	M:HV102	M:HV202	AIRCO dipole	
PQ3	M:Q103	M:Q203	3Q120 quad	
PQ4	M:Q104	M:Q204	3Q120 quad	
PQ5A	M:Q105	M:Q205	3Q120 quad	
PQ5B	M:Q105	M:Q205	3Q120 quad	
PQ5-HT	M:HT105	M:HT105	35” bump	
PBV1	M:V105	M:V205	AIRCO dipole	
PBV2	M:V105	M:V205	AIRCO dipole	
PQ6A	M:Q106	M:Q206	3Q120 quad	
PQ6B	M:Q106	M:Q206	3Q120 quad	
PQ7A	M:Q107	M:Q207	3Q120 quad	
PQ7B	M:Q107	M:Q207	3Q120 quad	
EB6		D:H926	SDD dipole	OFF for stacking, critical device
PQ7-HT	M:HT107	M:HT107	35” bump	
PQ8A	M:Q108	M:Q208	3Q120 quad	
PQ8B	M:Q108	M:Q208	3Q120 quad	
PQ8-VT	M:VT108	M:VT108	40” bump	
PQ9A	M:Q109I, M:Q109V	M:Q209	3Q120 quad	
PQ9B	M:Q109I, M:Q109V	M:Q209	3Q120 quad	

Table 2 AP1 Magnetic Elements

1. 120 GeV

120 GeV protons from the Main Injector are extracted in a single turn initiated by a kicker located at MI-52. A series of Lambertson magnets downstream of the kicker bends beam vertically into the P1 line. Beam is directed down the P1 line, then passes into the P2 line at F0 in the Tevatron enclosure. A Lambertson magnet at F0 directs beam downward into the Tevatron when it is powered, so it's left off when beam is desired in the P2 line. The P2 line, sometimes referred to as the "Main Ring remnant", transports the beam between F0 and F17 where the AP-1 line begins. Although Lambertson magnets are no longer required to bend beam into the AP-1 line, (conventional dipoles would suffice) the original F17 Lambertson magnets remain. With the decommissioning of the Main Ring, the Lambertsons were moved horizontally so that beam always passes through the center of the field region (see Figure 6.4). If beam is destined for the P3 line, the Lambertsons are simply not powered. The two Lambertson magnets and the two 'C' dipoles that follow are powered in series at 120 GeV by a single power supply located at F2 known as M:F17LAM. It is a former Main Ring bend power supply, which has been specially modified for its current use. When stacking, the magnets are ramped to reduce power consumption as well as to reduce the heat load on the magnets. Additionally, the magnets powered by M:HV100 and M:HV102 are also ramped (via 165 cards) to reduce cable heat load and conserve power.

2. 8 GeV

AP1 magnets are run at a much lower current for 8 GeV than 120 GeV operation. It would be prohibitively expensive to have power supplies designed to regulate well at both current levels so separate power supplies are used for the two modes. Although M:HV100 and M:HV102 are ramped for 120 GeV operation, M:HV200 and M:HV202 are run DC for 8 GeV beam.

When AP1 is used to transfer pbars into the Main Injector, the first four quadrupoles, PQ7A&B (M:Q207) and PQ6A&B (M:Q206), encountered by the antiproton bunches are used to match the optics of AP1 and AP3. Note that PQ8A&B (M:Q208) and PQ9A&B (M:Q209) are bypassed by the AP3 line, the 8 GeV supplies are only needed on the infrequent occasions when 8 GeV protons are transferred to the Debuncher via AP2.

The AP1 lattice is altered for 8 GeV operation by reversing the polarity of PQ2 (the quadrupole is changed from horizontally defocusing to horizontally focusing). Since the quadrupole power supplies are not bipolar, a separate reversing switch, M:Q102R, is used for the polarity reversal. This switch was added after the first collider run to reduce the size of the extracted beam at PQ3. The original lattice design had caused poor efficiency during antiproton transfers.

E. AP2

Following the lithium lens (D:LNV) in the target vault, a pulsed 3 degree horizontal dipole known as the Pulsed Magnet (D:PMAGV) is used to momentum select negatively charged 8 GeV secondary particles into the AP2 line. The AP2 line then transports the selected particles towards the Debuncher. Most of the secondaries other than antiprotons have a short lifetime and decay during the journey down this beamline. Whatever is left, mostly pions and electrons, does not survive the first few turns in the Debuncher. AP2 was designed to transport an 8 GeV beam with 20π mm-mrad (190π mm-mrad normalized) transverse emittance and a momentum spread of 4%. Table 3 lists the magnetic elements making up the AP2 line.

According to the *Tevatron I Design Report*, the AP2 line can be broken into five parts. The first section, beginning with the Pulsed Magnet, is described as the "clean-up" section. After exiting the target vault, the AP2 line passes through two pairs of quadrupoles and a vertical trim which is located between IQ2 and IQ3 (D:Q702). Another 3° bend to the left by IB1 completes this portion of the line.

A transport section follows, which consists of a FODO lattice of quadrupole cells. These periodic cells have a length of 89 feet. Pairs of horizontal collimators are located immediately downstream of IQ7 and IQ9 (D:Q707). Similarly, pairs of vertical collimators are positioned downstream of IQ8 and IQ10 (D:Q707). Two vertical and a horizontal trim dipole are contained in this section to fine tune beam position: IQ6-VT (D:VT706), IQ11-HT (D:HT711), and IQ11-VT (D:VT711).

Next is a left bend made up of six bending elements, IB2-7 (D:H717), which deflects the beam by 36.53°. Four quadrupoles are interspersed amongst these bending magnets. The elevated horizontal dispersion in the left bend section results in a large horizontal beam size. For this reason, momentum selection can be done in the middle of the section with a set of horizontal collimators.

Another long transport section follows, virtually identical to the first transport, made up of repeating FODO cells. A vertical and horizontal trim dipole are placed in this line downstream of IQ23 (D:Q716) and IQ27 (D:Q719) respectively. IQ24 is no longer connected electrically, it was originally powered by D:Q716 but was disconnected to improve the beamline lattice.

The final portion of the AP2 line is an achromatic vertical translation into the Debuncher called the "injector" section. The section ends at the downstream end of a 2.1 meter current septum magnet. Beam is deflected downward in this portion of the line with a 3.62° bending magnet, IBV1 (D:V730), and is translated 1.3 meters to be at the same elevation as the Debuncher. Three quadrupoles, IQ31-33 (D:Q731), are located in the injector section as well as a pair of horizontal trims, IQ30-HT (D:HT730) and IQ31-HT (D:HT731). A large quadrupole in the Debuncher, D2Q5, has a large aperture to accommodate both the circulating and extracted beam. This large quad is of the same design as those found in the Accumulator high dispersion areas. D2Q5 is powered by both D:IB and D:QT205 for a total of more than 1,500 A. The large quads have fewer windings than the small quadrupoles found at the other DxQ5 locations and require considerably more current to produce the same field strength. Because the AP-2 beampipe is offset from the center of this magnet, a dipole field is imparted on the injected beam providing an upward bend. A pulsed magnetic septum, ISEP (D:ISEPV), and 3-module kicker magnet, IKIK (D:IKIKV), complete the injection line.

Power supplies for AP-2 line magnets in the upstream part of the line are located in AP0, those located in the middle of the line can be found at F27, and downstream supplies reside in AP50.

ELEMENT	POWER SUPPLY	TYPE OF DEVICE	COMMENTS
IQ1	D:Q701	SQC	
IQ2	D:Q702	SQC	
IQ2-VT	D:VT702	NDB	
IQ3	D:Q702	SQC	
IQ4	D:Q701	SQC	
IB1	D:H704	modified B1	Critical device
IQ5	D:Q701	SQC	
IQ6	D:Q701	SQC	
IQ6-VT	D:VT706	NDB	
IQ7	D:Q707	SQC	
IQ8	D:Q707	SQC	
IQ9	D:Q707	SQC	
IQ10	D:Q707	SQC	
IQ11	D:Q707	SQC	
IQ11-HT	D:HT711	NDB	
IQ11-VT	D:VT711	NDB	
IQ12	D:Q707	SQC	
IQ13	D:Q707	SQC	
IQ14	D:Q707	SQC	
IQ15	D:Q715	SQA	
IQ16	D:Q716, D:QS716	SQB	
IQ17	D:Q716, D:QS717	SQD	
IB2	D:H717	6-4-120 wide gap	Critical device
IQ18	D:Q718	SQB	
IB3	D:H717	6-4-120 wide gap	Critical device
IB4	D:H717	SDE wide gap	Critical device
IQ19	D:Q719, D:QS719	SQB	
IQ20	D:Q719, D:QS720	SQB	
IB5	D:H717	SDE wide gap	Critical device
IB6	D:H717	6-4-120 wide gap	Critical device
IQ21	D:Q718	SQB	
IB7	D:H717	6-4-120 wide gap	Critical device
IQ22	D:Q716, D:QS722	SQD	
IQ23	D:Q716, D:QS723	SQD	
IQ23-VT	D:VT723	NDB	
IQ24		SQA	not powered
IQ25	D:Q716	SQD	
IQ26	D:Q719, D:QS726	SQA	
IQ27	D:Q719	SQA	
IQ27-VT	D:HT727	NDB	
IQ28	D:Q719, D:QS728	SQA	
IQ29	D:Q729, D:QS729	SQD	
IQ30	D:Q729, D:QS730	SQD	
IBV1	D:V730	modified B1 wide gap	Critical device
IQ30-HT	D:HT730	vernier trim	
IQ31	D:Q731, D:QS731	SQE	
IQ31-HT	D:HT731	vernier trim	
IQ32	D:Q731, D:QS732	SQE	
IQ33	D:Q731, D:QS733	SQE	
D4Q5	D:QT405, D:IB	LQE	
ISEP	D:ISEPV	pulsed septum	
IKIK	D:IKIK	3-module kicker	

Table 3 AP2 Magnetic Elements

F. Debuncher to Accumulator (D to A)

Beam is transferred horizontally from the Debuncher into the Accumulator in the 10 straight section. Extraction from the Debuncher is accomplished with a 3-module kicker, EKIK (D:EKIKV), and septum, ESEP (D:ESEPV) combination. The quadrupole in the Debuncher just downstream of the septum, D6Q6, is a large style quadrupole used in much the same way as D2Q5 is at the end of the AP2 line. In this case beam passes horizontally off-center through D6Q6 providing a greater bend towards the Accumulator. The D to A line has a vertical trim between the first two quadrupoles, and a horizontal trim between the second and third quadrupoles. Another vertical trim as well as a major bend, TB1&2 (D:H807A&B), are found between the sixth and seventh quadrupoles. The vertical trims can be used together to control the vertical position and angle at injection into the Accumulator. The two horizontal dipoles can control the horizontal position and angle at injection. Beam passes through a septa pair, ISEP2 (A:ISEP2V) and ISEP1

ELEMENT	POWER SUPPLY	TYPE OF DEVICE	COMMENTS
EKIK	D:EKIK	3-module kicker	
ESEP	D:ESEPV	pulsed septum	
D6Q6	D:QT606, D:IB	LQE	
TQ1	D:Q801, D:QS801	SQE	
TQ1-VT	D:VT801	NDB	
TQ2	D:Q801, D:QS802	SQD	
TQ4-HT	D:HT804	NDB	
TQ3	D:Q801	SQD	
TQ4	D:Q804, D:QS804	SQC	
TQ5	D:Q804	SQD	
TQ6	D:Q804, D:QS806	SQD	
TQ6-VT	D:VT806	NDB	
TB1	D:H807A	modified B1	
TB2	D:H807B	modified B1	
TQ7	D:Q807	SQA	
ISEP2	A:ISEP2V	pulsed septum	
ISEP1	A:ISEP1V	pulsed septum	
IKIK	A:IKIKV	shuttered kicker	

Table 5 D to A line Magnetic Elements

(A:ISEP1V), and then is kicked onto the Accumulator injection orbit with a shuttered kicker, IKIK (A:IKIKV), in the A20 high dispersion straight section. All D to A line power supplies are located in the AP10 service building except A:IKIKV which is located at AP-30.

G. AP3

This transport line can be separated into five sections: extraction, a long transport, a left bend, another long transport and a target bypass. When beam is extracted from the Accumulator, a shuttered kicker in the A20 high dispersion straight section kicks beam on the extraction orbit (radially outside) horizontally so that when the kicked beam reaches straight section 30 it passes through the field region of a Lambertson magnet, ELAM. Both the extraction and injection kickers used in the Accumulator have shutters to prevent the core from being disturbed by fields from the kicker. A metal shutter moves into the aperture between the injection/extraction orbit and the high-energy edge of the stack tail shortly before the kicker fires and retracts afterwards. ELAM bends beam upwards and out of the Accumulator and a 'C' magnet just downstream of the Lambertson supplies an additional upward bend. These devices, both powered by the D:ELAM power supply, raise the extracted beam to a level four feet above the Accumulator. Two separate downward bends, EBV1&2, of 50 mrad each level the extracted beam at the same height as the production target. In the extraction channel there are also five quadrupoles, EQ1, 2, 3A&B, and EQ4, and a horizontal trim, EQ1-HT.

ELEMENT	POWER SUPPLY	TYPE OF DEVICE	COMMENTS
EKIK	A:EKIK	shuttered kicker	
ELAM	D:ELAM	80" Lambertson	
C- magnet	D:ELAM	30" 'C' magnet	
EQ1	D:Q901	SQC	
EBV1	D:V901, D:VS901	modified B1	Critical device
EQ1-HT	D:HT901	NDB	
EQ2	D:Q901	SQD	
EQ3A	D:Q903	SQD	
EQ3B	D:Q903	SQD	
EQ4	D:Q901	SQB	
EBV2	D:V901, D:VS904	modified B1	Critical device
EQ5	D:Q901	SQC	
EQ6	D:Q901	SQD	
EQ6-HTA	D:HT906A	40" bump	
EQ6-VT	D:VT906	NDB	
EQ6-HTB	D:HT906B	NDB	
EQ7	D:Q907	SQE	
EQ8	D:Q907	SQA	
EQ9	D:Q909	SQA	
EQ10	D:Q909	SQA	
EQ10-HT	D:HT910	NDB	
EQ11	D:Q909	SQA	
EQ12	D:Q909	SQA	
EQ13	D:Q913	SQA	
EQ14	D:Q914	SQA	
EB1	D:H914	SDE	Critical device
EQ15	D:Q913, D:QS915	SQC	
EB2	D:H914	SDE	Critical device
EQ16	D:Q916	SQC	
EB3	D:H914	SDE	Critical device
EQ17	D:Q917, D:QS917	SQA	
EQ17-VT	D:VT917	NDB	
EQ18	D:Q917	SQA	
EQ19	D:Q919, D:QS919	SQB	
EQ20	D:Q919	SQA	
EQ21	D:Q919	SQA	
EQ22	D:Q919	SQA	
EQ23	D:Q919	SQA	
EQ24	D:Q924	SQA	
EQ25	D:Q924, D:QS925	SQA	
EQ25-VT	D:VT925	NDB	
EB4	D:H914, D:HS925	SDE	Critical device
Target bypass			
EQ26	D:Q926, D:QS926	SQB	
EB5	D:H926	SDD	
EQ27	D:Q926	SQC	
EQ28	D:Q926, D:QS928	SQD	
EB6	D:H926	SDD	

Table 4 AP3 Magnetic Elements

After the down/leveling bends, beam passes through the first long transport consisting of ten quadrupoles, EQ5-14. This has a repeating FODO lattice similar to the long transport sections of the AP2 line, although the cell length is longer. A cluster of three trims, EQ6-HTA, EQ6-VT, EQ6-HTB, is located at the upstream (as seen by pbars) end of this section.

A bend to the left, EB1-3, follows. There are two quadrupoles. EQ15, 16, located in the bend section. Beam then is directed through a second long transport, which is similar to the previous one. This long transport runs parallel to the first long transport in the AP2 line. This section includes nine quadrupoles, EQ17-25, and vertical trims, EQ17-VT & EQ25-VT, at each end.

The AP3 line then bypasses the target by means of an achromatic transport using three dipoles and three quadrupoles, EQ26-28. The first of the three dipoles, EB4, is electrically connected with EB1-3 which make up the left bend. Following EB4, AP3 departs the Transport enclosure and bypasses the target station. After the target bypass, AP3 beam enters the Prevault enclosure and encounters two bends, EB5&6, which direct beam into the AP1 line. The final dipole of the target bypass, EB6, is actually in the AP1 line between the tenth and eleventh quad (in the proton direction) of that line. Since it is physically in the AP1 line, its power supply, D:H926, must be off during 120 GeV operation or during studies periods when beam is desired to pass through the target vault.

Three service buildings house AP3 line power supplies: AP30 for the upstream end, F27 for the bulk of the supplies, and AP0 for the downstream portion.

H. Decommissioned beamlines

1. The original AP-1 line

Early designs of the AP-1 line were based on a proton energy of 80 GeV from the Main Ring. The energy was later raised to 120 GeV in order to increase the target yield. Increasing the energy of the proton beam incident on the target increases the yield of 8 GeV antiprotons but also requires a longer Main Ring cycle time. Calculations suggested that a beam energy of 120 GeV was the practical upper limit for extraction energy from a medium straight section. Improvements in the rate of rise of the Main Ring ramp allowed the increase to 120 GeV. However, it also complicated the process of extracting the Main Ring protons and delivering them to the target.

An 80 GeV line existed at one time in the Tevatron enclosure, perched just above the Main Ring and extending from F-17 to F-25. When the increase in proton energy was first proposed, the original plan was to upgrade the 80 GeV line for 120 GeV operation. There were problems with this approach, as the magnets would have been run at a substantially higher current, resulting in a large increase in power consumption. The existing beamline magnets were difficult to maintain and also made work on the Main Ring and Tevatron magnets more complicated. When the Tevatron was installed, the 80 GeV line had to be dismantled to allow enough room to work.

The original pbar target hall, which is in a field outside the Tevatron enclosure near F-26, limited the ability to vary the position on the target. The 80 GeV line had originally been put into the Main Ring tunnel because of the operating schedule. In 1977-78 there was not enough time available to modify the tunnel at F-18 in order to build the more elaborate beamline. Eventually, the problems associated with the higher energy proton beam helped make the decision to build a more efficient and flexible beamline. The new design resulted in a four-fold reduction in power consumption (not only lower energy costs, but smaller and less expensive power supplies) over what an upgraded 80 GeV line would have used.

In the original 120 GeV beam line scheme, a tunnel was to run from the Main Ring to the target vault. There was also to be a separate enclosure to run adjacent to the vault where AP-3 is situated. However, the final beamline includes a "sewer pipe" through which the beampipe passes in AP-1 from the Main Ring to the Pre-Target enclosure. There is no separate enclosure where AP-3 bypasses the target vault, it simply passes through part of the vault.

2. AP-4

The AP4 line was used to transfer 8 GeV protons from the Booster to the Debuncher. This permitted beam studies during periods of extended Main Ring down time when the Booster was operational. Since the protons circulated in the same direction as pbars would have, the power supply/magnet polarities were reversed.

Booster beam was extracted upwards at Long 3 and bent back downwards by a vertical dipole. A vertical dogleg followed the dump and lifted beam to the level of the rings enclosure. Beam was transferred through a "sewer pipe" from the Booster to the rings enclosure. The extraction point from Booster for the former AP-4 line is now used for the MI-8 line. In the Pbar rings enclosure, evidence of the AP-4 line can be found at the upstream end of the 20 sector on the outside of the enclosure. The Debuncher location formerly used by the injection kicker is now occupied by a cooling kicker tank. Even before AP-4 was decommissioned, the kicker was replaced with the cooling tank during running periods. A "large" quad is still in place at D2Q5 where the descending beamline passed through the upper aperture. Like large quads associated with the AP-2 and D/A lines, this quad is powered by a combination of D:IB and a separate supply D:QT205.